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X-RAY COMPUTED TOMOGRAPHY FOR GEOMETRY ACQUISITION

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X-ray computed tomography (CT) provides quantitative measures of component feature dimensions and density as related to the linear X-ray attenuation of the material under study. The data are available in digital format to be input not only to NDE workstations but also design workstations. By converting the CT data to computer aided design/engineering (CAD/E) workstations, the designer/engineer can access the as-built component geometry. Productivity gains are realized in generating computer drawings for as-built components. In the case of components that do not have adequate drawing documentation, particularly ergonomically, aesthetically or aerodynamically shaped parts, the CT data provide a highly cost effective approach for generating digital format documentation.

Multiple slice CT data may be used to completely define the object, or CT data at selected orientations may be used to define specific features. Once data are transferred to a workstation, the designer can manipulate the data to create a part drawing. The process of obtaining digital definition of an existing component is referred to as geometry acquisition.

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SUMMARY

X-ray computed tomography (CT) provides quantitative measures of component geometry and density by providing 3-D maps of the linear X-ray attenuation of the materials in the CT scanner field of view. The data are available in digital format to be input not only to NDE workstations but also design workstations. By converting the CT data to computer aided design/engineering (CAD/E) workstation format, the designer/engineer can access the as-built component geometry. Productivity gains can be realized in generating computer drawings for as-built components faster and more accurately than alternative approaches. In the case of components that do not have adequate drawing documentation, particularly ergonomically, aesthetically or aerodynamically shaped parts, the CT data provide a highly cost effective approach for generating digital format documentation.

Multiple slice CT data may be used to completely define the object, or CT data at selected orientations may be used to define specific features. Once data are transferred to a workstation, the designer can manipulate the data to create a part drawing. The process of obtaining digital definition of an existing component is referred to as geometry acquisition.

DISCLAIMER

1.0 INTRODUCTION

The goal of the Advanced Development of X-Ray Computed Tomography Applications demonstration (CTAD) program is to identify applications in the aircraft industry where X-ray computed tomography (CT) provides a cost benefit. The CTAD program investigated a number of potential areas in task assignment studies and prepared interim reports detailing the application of CT to the areas under study. Geometry acquisition for computer aided design/engineering was identified as a useful application of CT. This interim report discusses the geometry acquisition process and includes examples from several task assignments. Additional task assignment reports that have been issued by the CTAD program are listed in References 1 through 13.

1.1 Computed Tomography

X-ray computed tomography (CT) is a powerful nondestructive evaluation technique that was conceived in the early 1960's and has been developing rapidly ever since. CT uses penetrating radiation from many angles to reconstruct image cross sections of an object. The clear images of an interior plane of an object are achieved without the confusion of superposition of features often found with conventional film radiography. The CT images are maps of the relative linear X-ray attenuation coefficient of small volume elements in the object. The X-ray linear attenuation coefficient measurement is directly related to material density and is a function of the atomic number in the small volume elements. The volume elements are defined by the reconstruction matrix (in combination with the X-ray beam width) and by the effective CT slice height. The CT image contains quantitative information about the density/constituents and dimensions of the features imaged. Processing the CT material density map to produce a digital representation of component surface contours and transferring the data to computer aided design/engineering workstations is called geometry acquisition.

CT systems are designed and built in a wide range of sizes for different purposes. Medical systems are designed for high throughput and low dosages specifically for humans and human sized objects. These systems can be applied to industrial objects that have low atomic number and are less than one-half meter (20 inches) in diameter. Industrial CT systems vary in sizes from the inspection of small jet engine turbine blades using mid-energy (hundreds of keV) X-ray sources to the inspection of large ICBM missiles requiring high (MeV level) X-ray energies. Industrial CT systems generally have much less throughput than medical systems. The CTAD program utilizes a wide range of CT systems, both medical and industrial.

1.2 Scope and Objective

This report, "X-Ray Computed Tomography for Geometry Acquisition," is an interim report discussing the applicability of CT for obtaining data to be used in computer aided design/engineering (CAD/E) workstations. The scope of this report is the collection of geometry acquisition applications from the various task assignment activities into one document. The objective is to provide the reader with examples of how CT can be applied as a useful geometry acquisition tool.

2.0 TEST PLAN

The test plan for geometry acquisition demonstrations consisted of obtaining samples of various types and evaluating the process of transferring data files to CAD/E workstations.

2.1 Component Selection

The samples examined are listed in Table 2.1-1. They consisted of a variety of types of components that had no drawings, were ergonomically or aerodynamically shaped or required dimensional measurement.

Table 2.1-1 Components Selected For Evaluation

PID	Description	Purpose of Evaluation
030189	Discharge Fitting	Dimensional measurement
030190	B-17 Tail Wheel	No drawings exist
-	Flight control wheel	Ergonomic shape
-	Inlet Duct	Aerodynamic shape

2.2 CT Testing

CT testing was performed at appropriate facilities based on the capability of the systems, the availability and cost. The quality of the CT imaging is not unique to any particular system utilized but in fact should be obtainable by alternative CT systems that have nearly equivalent resolution and contrast sensitivity for the component size under examination. In general the system types are categorized as medium resolution industrial CT (400 kV_{peak}, roughly 1 line pair/mm and 20 to 100 signal-to-noise ratio), high resolution industrial CT (400 kV_{peak}, 2 to 4 line pair/mm and 5 to 20 signal to noise ratio) and medical CT (120 kV_{peak}, roughly 1 line pair/mm and 50 to 150 signal-to-noise ratio).

2.3 Data Evaluation

The nature of the CT data allows for a quantitative measure of features in terms of dimensions and X-ray attenuation. The CT data can be conditioned by appropriate edge finding routines and the data transferred into a CAD/E system. This data can be further reduced to contours and a wireframe model for CAD manipulation; part drawings can then be created. Evaluation of the CT results consisted of assessment of the validity of the drawing created and the cost benefit of the process.

3.0 GEOMETRY ACQUISITION PROCESS

3.1 Background

There are many instances in which the geometry of a part cannot be adequately defined in a drawing before fabrication or completely measured after manufacture by conventional means. This is especially true for both aerodynamic and ergonomic surfaces. These surfaces tend to be complex in nature and difficult to define on paper or digitally in a computer. Attempts to use coordinate measuring machines or optical scanners to provide the digital coordinate data have often proved to be expensive and time consuming, except for relatively simple exterior surfaces. In addition, they have either under-defined or were unable to define all the required geometry in complex parts, especially if interior dimensions or contours are required. The data that is generated from these other methods can also be difficult and costly to deal with because they are discrete points measured on a surface in 3-dimensional coordinates. Often, only reasonable approximations for the actual surfaces are used, and/or the part is never properly defined in the documentation. The most conventional approach of cutting and physically measuring dimensions of complex parts also suffers from excessive time to acquire and input the data by hand, as well as a lack of accuracy of details.

3.1 CT Measurements

CT uses penetrating radiation to generate a nondestructive cross-sectional image of a component, defining internal and external features equally well. CT also is performed within a known 3-dimensional space, such that all positions in the object are known relative to a common origin. Provided the object can fit within the field of view of the CT scanner and be imaged without excessive image reconstruction artifacts, CT offers an excellent technique for defining the exterior and interior geometry of components. The use of CT images for dimensional measurements is a very common industrial application [14-18]. The logical extension of this capability is to convert the image data into line drawing format for analysis in engineering workstations [18, 19-21]. Geometry acquisition is the process of creating data files that can be used in a CAD/E environment. Geometry acquisition is valuable for parts that are ergonomically, aesthetically or aerodynamically shaped, in order to obtain a digital model of a part whose form could not be defined mathematically in an original drawing. Parts for which drawings do not exist or are not accurate due to processing steps also benefit from geometry acquisition.

Although in principle CT could be used to acquire digital geometry for any article, there are constraints of available hardware, software and accuracy requirements which influence the actual approach. For hardware, medical CT scanners or industrial scanners can be used to acquire the initial data depending on the size and material of the article. Medical scanners provide a much faster throughput than industrial scanners. Industrial scanners can provide much greater penetration and can handle large objects or provide finer resolution for very small objects. The dimensional measurement accuracy requirement for the articles examined to date has been 0.5 mm (0.020 inch) tolerance, which is readily achievable with medical or industrial CT systems. Measurements with accuracies on the order of 1 part in 5000 should be possible for most objects.

The conversion of the CT density map into component surface contours requires the definition of the edge of the part. The software method most commonly used to determine the location of the part edge in the CT slice frame of reference is thresholding directly on the density (choosing the edge to be located at the position where the density is midway between the CT value for the material and the surrounding air, i.e., 50 percent threshold). The component surfaces to be defined should be composed of a single material in order for the edge finding to work well.

When multiple materials are present at different locations along the edge of a part, a single threshold value may be correct for one material but will not be correct for the other. The accuracy of measurements using the 50 percent threshold approach was discussed in referenced reports and articles [8,17,18]. For articles composed of multiple materials, more sophisticated methods should be used, such as the gradient magnitude approach. With this method the edge is defined by the maximum of the slope (first derivative) of a line trace across the component edge. The materials, however, must still be of reasonable homogeneity and relatively void free. In the case of a model which was composed of wood (0.2-0.5 g/cm^3), aluminum (2.7 g/cm^3), auto body putty (4.0-4.5 g/cm^3) and steel (8.7 g/cm^3) the gradient magnitude approach would not work. Other edge finding approaches are available, but significant evaluation and optimization of the algorithms to handle a variety of complex materials such as porous, low density wood is needed.

3.3 CT Geometry Acquisition Steps

The process of employing CT for geometry acquisition requires the selection of a test or scan plan. This involves the definition of the surfaces that must be defined, how they will be obtained from the CT scanning and how the data must be reduced on the CAD workstation. One approach is to transfer piecewise linear string contour data from each CT slice to the CAD workstation, then, utilizing the capabilities of the CAD system, form idealized contours (with splines and straight lines). Finally, spines are added to the CAD model to tie the CT slice contours together. The number of CT slices and their orientation are defined by the designer who will use the data to create the final CAD model. Alternatively, one can transfer piecewise linear surface contour data from a complete volume CT data set if computational resources permit.

The process steps for CT geometry acquisition, using the slice-by-slice approach, are listed in Table 3.3-1. First, the object will be scanned on a CT system. The object may be scanned with one or more single slices at various planes or locations on the part, or in a series of scans which covers the part completely in three dimensions. The first case would apply to parts that have global symmetries and which may also have regions where particular geometric detail is needed. The second case would apply to parts that have a continually varying, undefined geometry, such as an ergonomic or aesthetic design. In this effort, initial processing of the scan data was performed using the Boeing INDERS NDE data processing software [22].

Table 3.3-1 Geometry Acquisition Process Steps

Step	Activity	Boeing Code/Process
1	CT scan object and format images (transfer CT images into neutral file format)	INDERS (neutral file format)
2	Form image contours a. thresholding for edge finding b. remove collinear points	IGES1024COLIN
4	Convert to IGES format	IGESTRY
5	Transfer to CAD workstation	ETHERNET

The INDERS software allows the conversion of CT images from any suitable CT system to a neutral file format for handling in subsequent steps. After tne CT grayscale images are formatted, the IGES1024COLIN code will create contours. This code typically operates on 1024 x 1024 images. The edge contours are found using the 50 percent thresholding approach.

The contours that are generated in step 2 of the process consist of piecewise linear strings connecting points. The contours contain a very large number of points due to the high definition (number of pixels) from the CT data set. This data set, however, can be compressed by removing collinear points. The collinear point compression algorithm moves along each contour in the file, removing the middle point in a set of 3 when it is sufficiently close to the straight line between the first and third point to be considered collinear. The collinearity is a variable selected by the operator. Typically, values of 0.025 to 0.250 mm (0.001 to 0.010 inch) are selected.

Once the contours have been defined from each of the CT image cross sections, they are converted to the Initial Graphics Exchange Standard (IGES). The IGES format allows the cross section files to be transferred and read by CAD/E workstations. In the transfer, each CT slice is put in as a different layer in the CAD/E workstation. Essentially, the IGES files are piecewise linear strings containing points which have x, y and z values. When a series of CT slices are used to evaluate the object the slice height is z; therefore, each layer will have a different z value.

While the geometry acquisition process is reasonably straightforward in terms of data acquisition and data processing, it is important to realize that this is not a fully automated process and that engineering judgement is required. There are several reasons for this. First, the final geometry of an actual part will consist of its design plus the variation that occurs during manufacturing. Thus, if one obtains the as-built part geometry, it is exact for that part, but it is not necessarily the correct design. Second, when the contours from the CT data have been transferred in the CAD/E workstation to form a model, they are still in piecewise linear strings. These are very large data files in the workstation. Therefore, the contours should be converted to straight lines, radii and splines and combined into one element. Engineering judgement is important at this point to use acceptable approximations which will simplify the model without adversely affecting the form, fit, function or manufacturability of the part. Third, depending on the part shape, material and CT system, artifacts will exist in the image which may be severe enough to influence the shape of the part in the edge finding algorithm. Artifacts are often a problem with parts that contain very long, straight sections. Engineering judgement can be used to correct the influence of common CT imaging artifacts on the geometry. Finally, CT may not define a complete part if only a few CT slices are used at various planes within the object. Fiducial marks or key features in the object must be recognized by an engineer in order to properly orient and utilize the cross sections in creating the CAD/E model.

CT actually overdefines the geometry in the piecewise linear strings. The workstation engineer will essentially extract information from the CT data to obtain the final model. It should be noted that it is much easier to delete information in a workstation than to generate input data, so CT data reduces the design effort when building a model of an existing part. The CT geometry acquisition data can essentially be used as templates for redefined contours in the workstation.

4.0 GEOMETRY ACQUISITION EXAMPLES

4.1 Discharge Fitting

Computed tomography for internal dimensional measurements of an object can be performed on the CT workstation at the time of scanning. However, the measurement capability can be enhanced by importing CT slices of a part into a CAD workstation and using CAD software to make the measurements. The advantage is that the data is translated into the form used by the design engineer to create the original part. The part has now come full cycle from the design, the manufacture and the nondestructive measurement, where the final measurement is available in the design engineer's workstation.

An example of this is the case of a cast aluminum discharge fitting. Figure 4.1-1 is a photograph of the discharge fitting. The critical design of the fitting is a tube divided into multiple passageways which discharge at different locations. Figure 4.1-2 is a digital radiograph of a portion of the discharge fitting showing locations where CT slices were taken to measure the internal condition of the passageways. An example of a CT slice is shown in Figure 4.1-3. In an earlier task assignment report the dimensional measurements on the casting walls were measured with CT and compared to physical measurements after the part was sectioned [13]. The CT measurements and physical measurements were within 0.25 mm (0.01 inch). Although dimensional measurements can be made on a CT system, there can be advantages to converting the data to CAD/E workstations. The conversion of the CT data to CAD format is straightforward using contour finding and IGES conversion. Once the data is modelled on the workstation, the section of the fitting can easily be measured for thickness, relative orientation of planes and radii of curves. Figure 4.1-4 is a CAD drawing from the CT image of the part (Figure 4.1-3) showing examples of the dimensional measurement possibilities. The advantage of this approach is that engineers can use the power of the workstation to gain information beyond the simple wall thickness measurements of the original CT image. On the workstation the shape of the curves and radii can be compared to the design. These data provide useful information about the processing of the part. When multiple parts are analyzed in this manner greater understanding and control of the process can be obtained. The dimensional measurements can include radii and angles as well as traditional wall thickness and spacing.

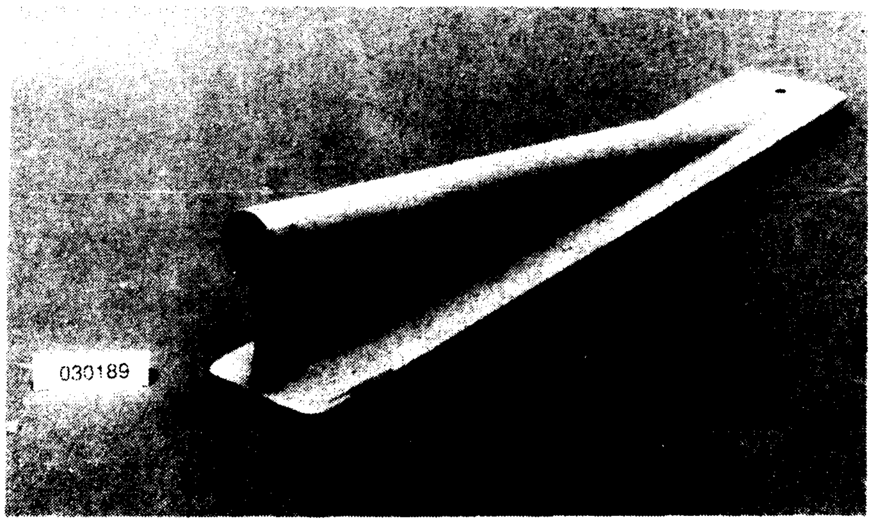

Figure 4.1-1 Photograph of a cast aluminum discharge fitting.

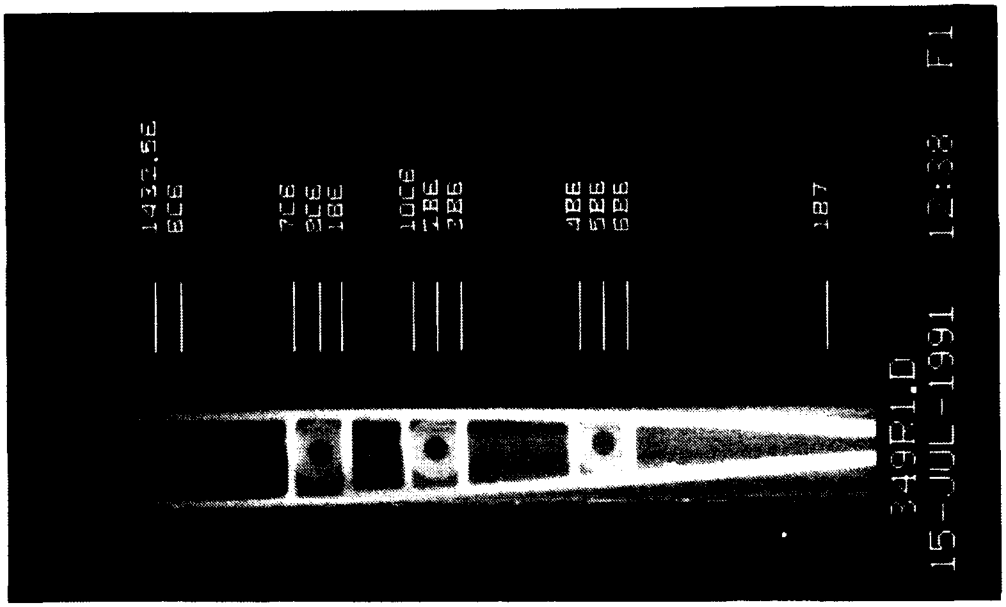

Figure 4.1-2 Digital radiograph of a portion of the discharge fitting showing location for CT slicing.

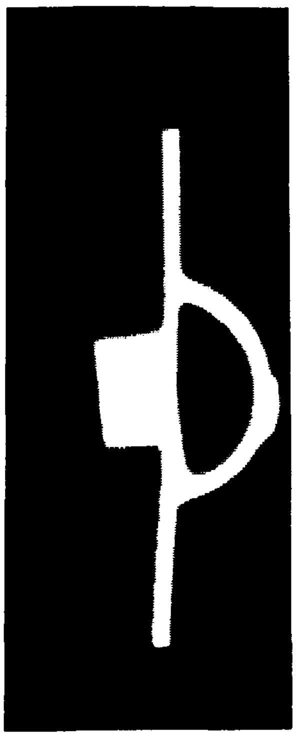

Figure 4.1-3 CT slice through the discharge fitting.

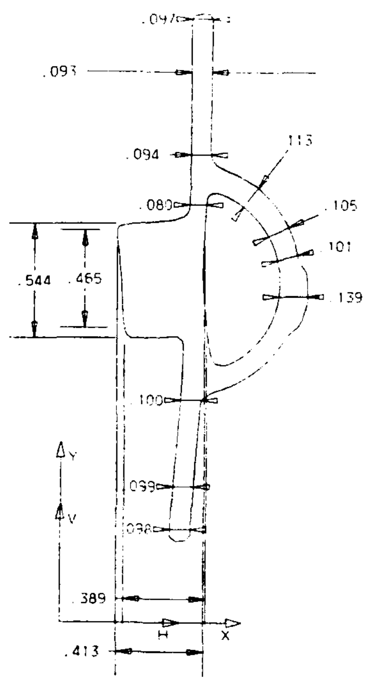

Figure 4.1-4 CAD model of a CT slice through the discharge fitting.

4.2 B-17 Tail Wheel

The B-17 tail wheel, of which only four tail wheels remain in existence, is an example of using CT for geometry acquisition to create a drawing for a part for which drawings no longer exist. One of the tail wheels was structurally evaluated using CT as part of an aircraft restoration project. The tail wheel is an aluminum casting approximately 290 mm (11.4 inch) long and 250 mm (9.8 inch) in diameter at the largest diameter end, shown in Figure 4.2-1. In addition to evaluating the internal quality of the cast aluminum tail wheel, several CT images were taken to provide the essential information necessary to construct a digital solid model.

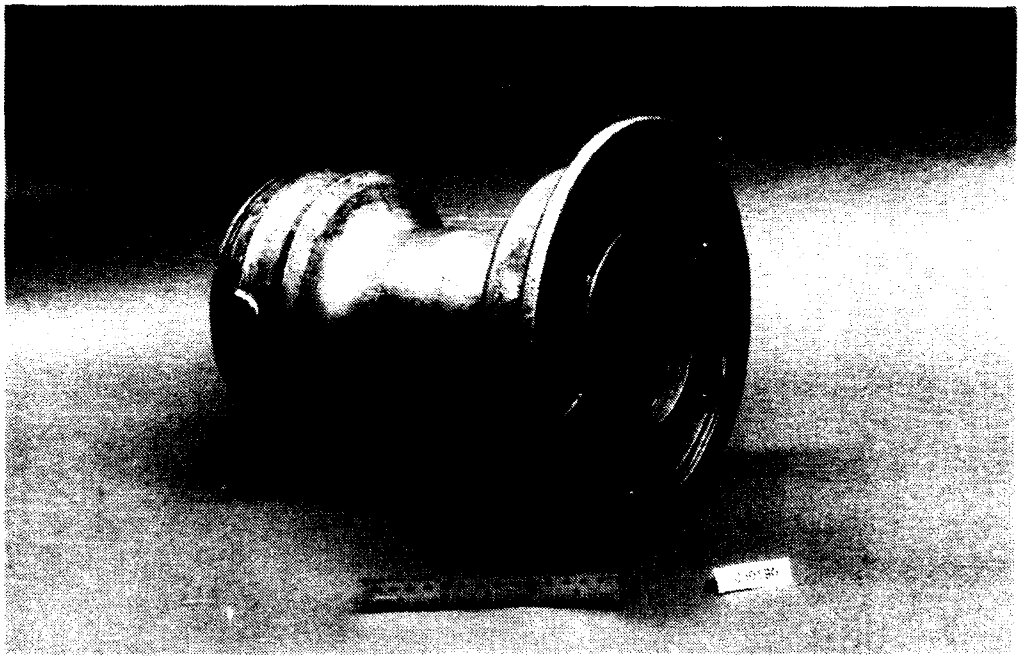

Figure 4.2-1 Photograph of a cast aluminum B-17 tail wheel.

Three longitudinal and two circumferential slices were taken to provide the information necessary to build the model. Figure 4.2-2 shows an example of a longitudinal CT slice of the tail wheel on the CT workstation. In Figure 4.2-3 a CT longitudinal data set has been transferred to a CAD/E workstation. At this point, the CT image has been converted into two contours. Since the tail wheel is a circularly symmetric part, an axis was defined midway between the bearing races on both ends of the wheel. Only 1 of the 2 contours was needed for further processing so one contour was deleted. Using the remaining single contour as a template, a new contour line was created using straight lines, radii and splines, shown in Figure 4.2-4. Engineering judgement was used to simplify the model without altering form, fit and function. This new contour was swept around the axis of symmetry to create a solid. Figure 4.2-5 shows a cutaway of the solid model and Figure 4.2-6 shows a wireframe version.

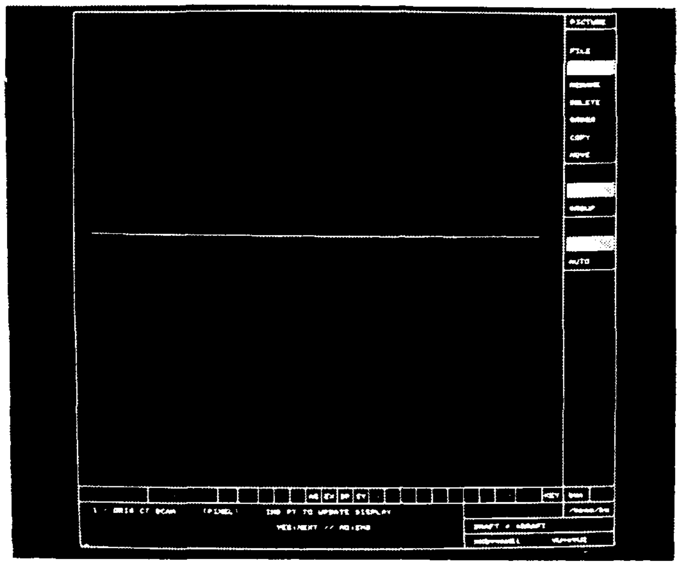

Figure 4.2-2 Example longitudinal CT slice of the tail wheel on the CT workstation.

Figure 4.2-3 CT data from a longitudinal CT slice in the CAD/E workstation.

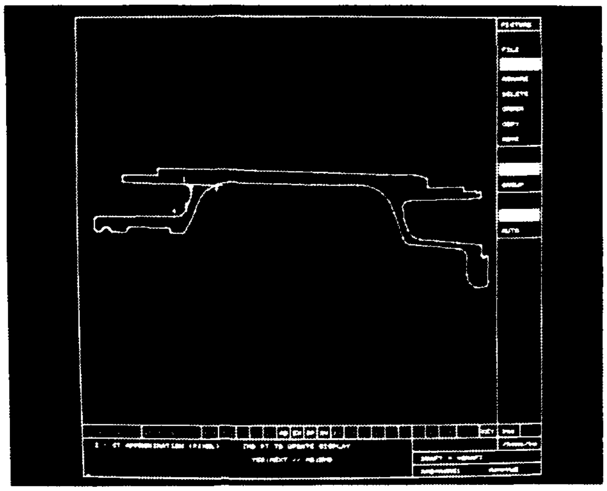

Figure 4.2-4 CT data set of one contour of the tail wheel converted to straight lines, radii and splines.

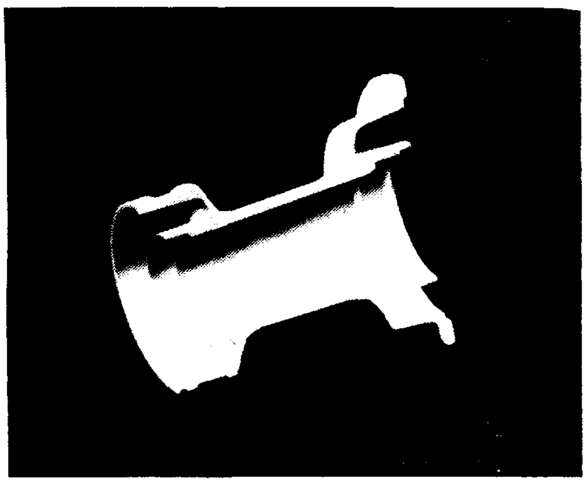

Figure 4.2-5 Cut away of the solid model.

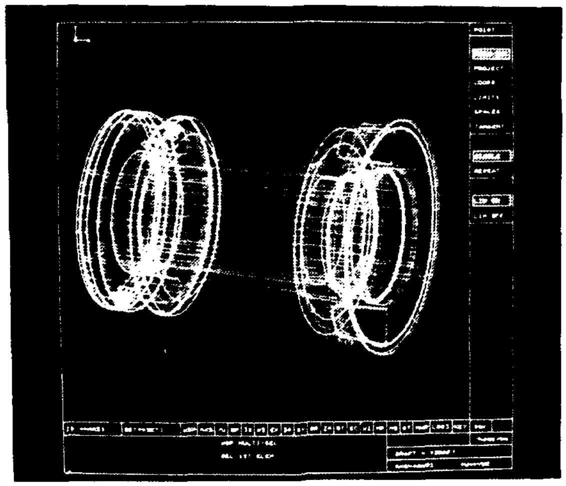

Figure 4.2-6 Wireframe model of the tail wheel.

At this point the model does not contain any details, so they must be added. The exact location and shape of details can be obtained from CT slices taken through the detail itself. The web, boss and valve stem holes were such details required for the tail wheel. The valve stem hole demonstrates the value of CT. Figure 4.2-7 shows the contour of the CT slice through the valve stem hole. The size and angle of the hole were easily determined from this data. However, on the actual part such a measurement would be considerably more difficult, particularly when determining the angle of the hole. In the workstation, a cylinder of the correct size and orientation was constructed and a boolean subtraction was performed on the solid model of the tail wheel to "drill" the hole out. The solid model of the complete tail wheel is shown in Figure 4.2-8.

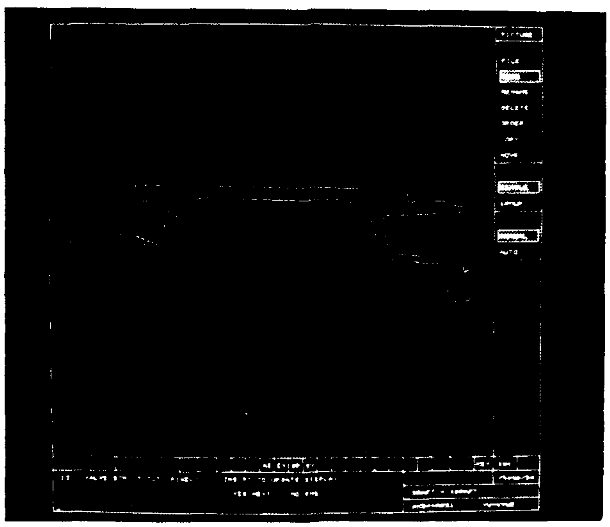

Figure 4.2-7 CT data transferred to the CAD workstation showing the valve stem hole position and orientation.

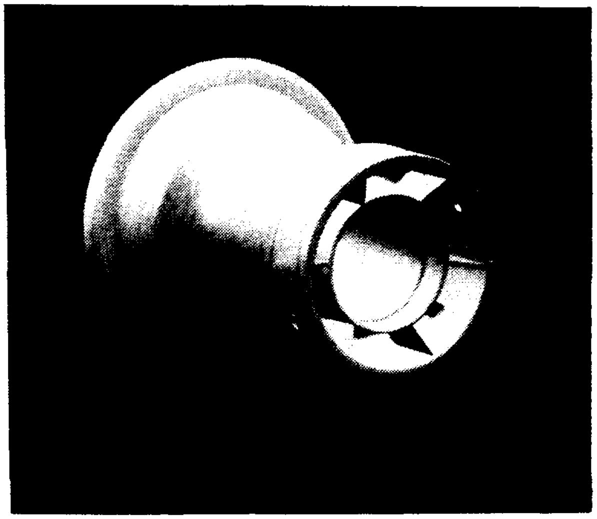

Figure 4.2-8. Solid model of the tail wheel in CAD/E workstation.

Once the solid model has been constructed in the CAD/E workstation, the design may be verified by having a rapid prototype model fabricated. Stereolithography has been used for this purpose [8]. Figure 4.2-9 shows the stereolithography model of the B-17 tail wheel made at one-half scale. The engineer can use the model to confirm that the digital design is correct. The combination of processes, manufactured part, CT data, CAD model and rapid prototype model all serve as tools which link the design, manufacturing and evaluation processes; thus ensuring that the model and manufactured parts are in agreement, satisfying the form, fit and function desired.

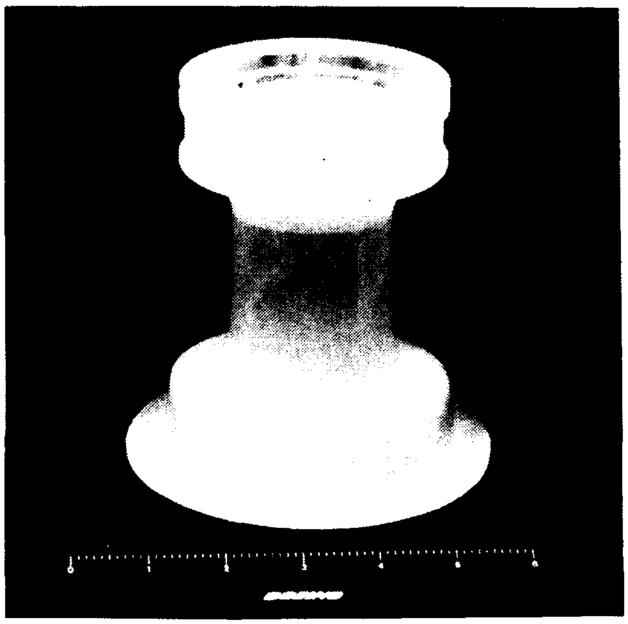

Figure 4.2-9. Stereolithography model of the tail wheel from the CAD model.

4.3 Flight Control Wheel

The tail wheel example has shown the use of selected CT slices for defining a part and building the drawing. In the case of a complete ergonomic shape, many CT slices may be required to define the shaped surfaces. The large CT data file model allows the designer to visualize the part very well, including interior features. This information would not be available from conventional dimensional measurement data acquisition approaches.

An example is the geometric acquisition of an ergonomically designed magnesium control wheel casting, shown in Figure 4.3-1. The master drawings of the control wheel were provided to a foundry that was being qualified as a new source. The result was a part that was acceptable per the drawing, but unacceptable when compared to the master model. The problem is that original drawings do not necessarily reflect the final master mold for components that are shaped to final ergonomic criteria. CT provides a method to retrieve the correct as-fabricated geometry. Other components such as aerodynamic surfaces have been equally successful in using CT for reducing the schedule and cost of geometry acquisition and improving the quality of the design process.

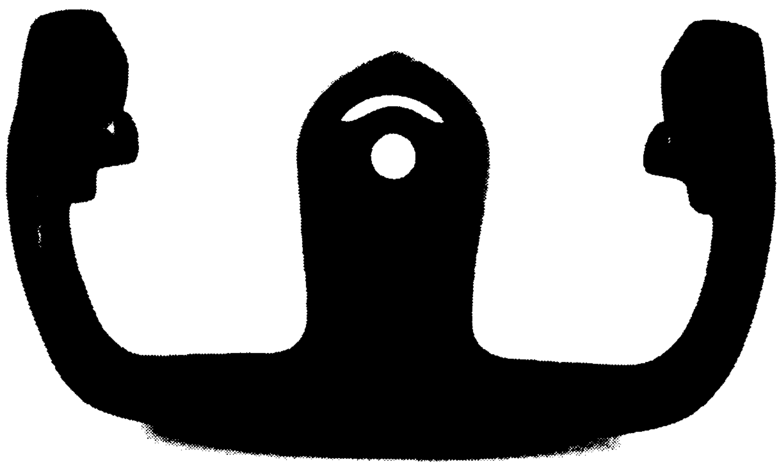

Figure 4.3-1 Photograph of an aircraft control wheel.

In the case of the aircraft control wheel, the scan plan called for 100 percent coverage of the part. To obtain this data in a reasonable time, a medical CT system was used. One hundred ninety-six (196) CT slices were taken, which formed approximately 800 contours that described the control wheel. Figure 4.3-2 shows the contours obtained from CT after they were converted to Initial Graphics Exchange Specification (IGES) format and transferred to a CAD workstation.

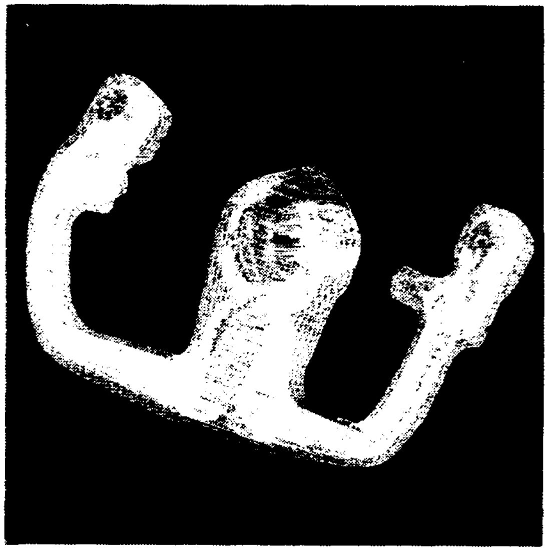

Figure 4.3-2 Contours for the control wheel after IGES transfer of 196 CT slices to a CAD workstation.

This data set is quite large and needs to be further reduced to be useful. Data reduction on the CAD workstation is performed by defining planes that cut through the contours, in the orientation where frames for the wireframe model were required. This process is the same whether the input data is from CT or other geometry acquisition methods. Figure 4.3-3 is an example of this activity. The new contours were reduced into points and idealized into straight lines, radii and splines to redefine the closed contour in a reduced data format. Approximately 80 to 120 wireframes were needed for the flight control wheel, which required approximately 0.5 to 1.0 hour each to build. Once a wireframe model was produced, it could be skinned and shaded as shown in Figure 4.3-4.

Figure 4.3-3. Example of the selection of defining planes for the wireframe model of a flight control wheel.

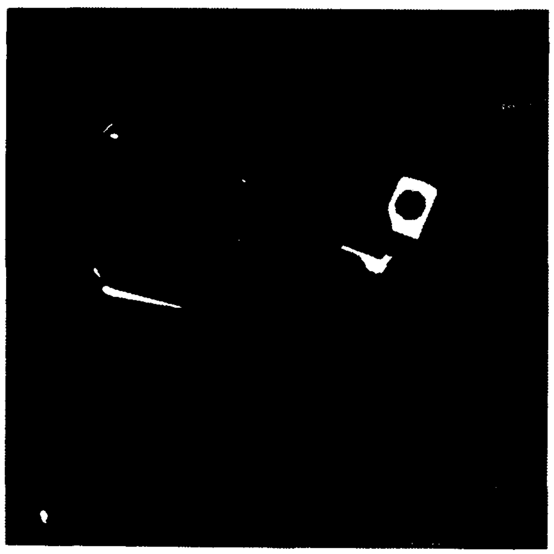

Figure 4.3-4 Shaded model of a control wheel in a CAD workstation.

4.4 Aerodynamic Shapes

Another example of using CT for geometry acquisition is the case of an aerodynamic shape. Aerodynamic surfaces are often shaped without a digital model. One particular example is a missile engine inlet duct, shown mounted on the CT system in Figure 4.4-1. The part was cast and then additional shaping processes were performed. The project further required that a mating surface be made. The construction of the mating surface CAD model would require a significant effort by conventional approaches. CT, however, offered a savings in schedule and effort to acquire the digital data.

A series of CT slices were taken over the region of interest. In this case, 36 CT slices were used to cover a length of about 500 mm (20 inches). The spacing of the center 28 CT slices, defining the most critical region, was 10 mm (0.4 inches); a larger spacing was used at either end. The CT data was thresholded, converted to IGES format and transferred to the CAD/E workstation. Figure 4.4-2 shows the drawing contours in the workstation.

Figure 4.4-1 Photograph of missile engine inlet duct.

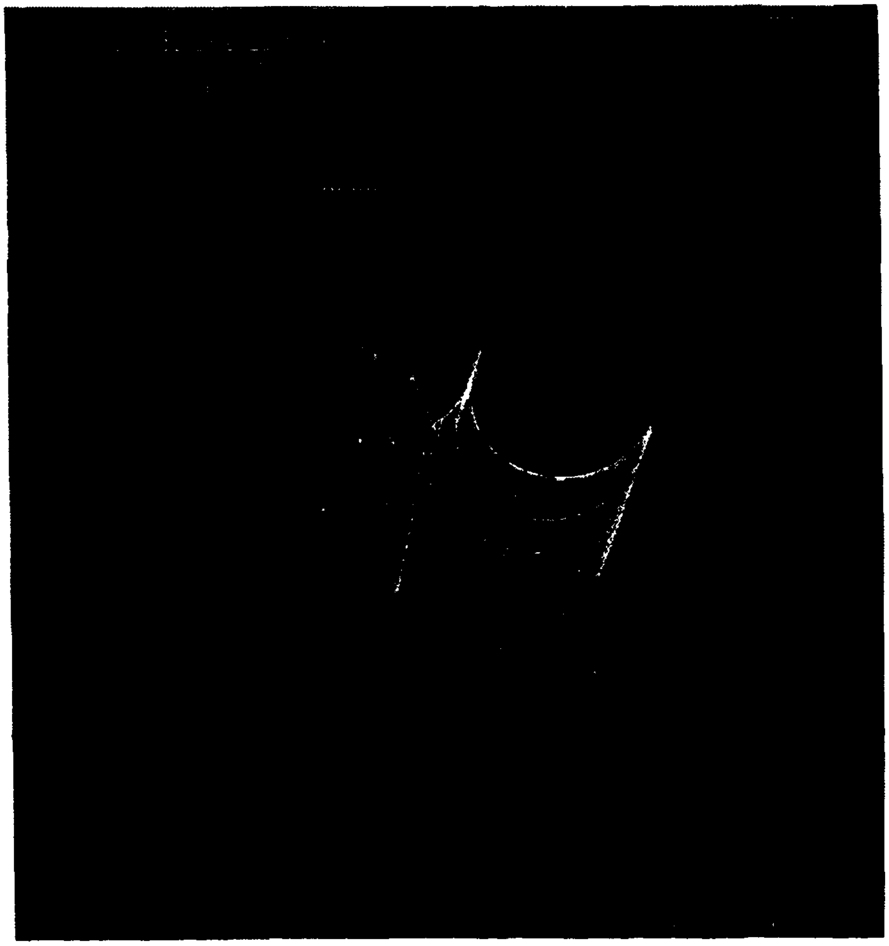

Figure 4.4-2 Drawing contours for the inlet duct surface in a CAD workstation.

5.0 COST BENEFIT ANALYSIS

CT can serve as a cost effective evaluation tool for acquiring digital data into CAD/E workstations. The areas in which CT can be of technical and economic value are dimensional measurements (particularly for internal cavities), and digital data acquisition for ergonomic, aerodynamic or aesthetic articles and components that have no digital design drawings. Defining complex shaped components digitally for input into CAD models for engineering design and assessment can be done using CT at a faster rate and at a lower cost than conventional methods, provided the material and size of the part are suited to the capability of available CT systems.

5.1 Tail Wheel

The B-17 tail wheel example is a relatively simple part for a designer to model in a CAD workstation. The availability of CT data provided a more accurate base to begin the model than a design engineer would traditionally have at his/her disposal. The data also saved sufficient effort to offset the cost of the CT data acquisition.

In this example the design engineer estimated that the total cost to construct the digital model, using CT data and a designer, is roughly equivalent to the cost of having a designer construct the model by traditional methods. However, the design engineer found that having the CT data was a preferable approach for reasons of accuracy and confidence. Further, as the object becomes more complex, the advantages of having CT data increase with a modest increase in cost, while the cost of traditional approaches on more complex structures would grow substantially.

5.2 Control Wheel

The cost of defining a control wheel using an optical surface measurement approach can be quite high compared to using CT. In one case, 450 engineering labor hours (estimated to be comprised of 200 hours dealing with the type and sparseness of the measuring machine data, and 250 hours to fully develop the surfaces of the wheel) and 120 shop hours (for measuring of the surface at approximately 200 discrete pre-selected points) were required for a symmetric (right/left mirror image) control wheel. CT geometry acquisition provided a 200-engineering hour and a 100-shop hour savings. (The 250 hours to fully develop the surfaces of the wheel are still required with the CT data set.) Additionally, the conventional method only provided definition of the external surfaces of a hollow cast part (the hollow portion is used for routing control wiring), while CT could define the interior surfaces as well. CT geometric acquisition represents a 300 out of 570 hours (53 percent) savings, or approximately $30,000.

For the nonsymmetric wheel, there would be a potential 600-hour savings for the total process by using CT for the geometry acquisition: both of the horns would be obtained directly by the CT data acquisition but each would require significant engineering effort in the optical acquisition case. Although a 600 hour savings is significant in cost, the 7 to 14 calendar week schedule required to do the work is often of more concern. The turnaround time for the CT geometry acquisition process was 1 calendar day after receipt of the model, with the availability of the CT facility scheduled in advance. This included the time required to have the data reduced and ready to load into the CAD workstation.

CT shows tremendous cost savings potential as a tool for geometry acquisition for a variety of ergonomically designed or complex shaped components.

5.3 Inlet Duct

The example of the aerodynamic surface model (an inlet duct) showed significant cost savings. The labor cost savings was approximately on the order of one-half; however, the schedule savings was substantially more significant. The original schedule for the activity using a surface profiling technique for data acquisition required an allowance of up to 2 weeks for completion of the task. The CT data acquisition and model construction were actually completed in 3 days. On a critical program the saving of a week or more can have enormous impact on the overall program cost.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Computed tomography is extremely well suited and valuable for geometry acquisition of appropriately sized parts. It provides measurements of both external and internal geometry. Processes for design and documentation of ergonomic, aesthetic and aerodynamically shaped parts, as well as parts for which drawings are unavailable, benefit from this technique. Although fully automatic data reduction and transfer probably can be performed by computer routines, engineering judgement is very important for cost effective development of the model on the CAD/E system for one-off or non-routine applications. The engineer can reduce the data sets into simple models by choosing appropriate straight lines, radii and splines to fit to the piecewise linear strings provided from CT. Also, engineering judgement is used to select the correct orientation of cross-sectional plane data, and to eliminate artifacts from the data.

Cost savings using CT have been found to be significant over other approaches for geometry acquisition on complex objects that are suitable for CT examination. Using current techniques, CT can generally be performed at a lower cost, in less time, and include interior features and relative optical or physical dimensioning. Compared to physical dimensioning of a part by a designer and hand input of the data into a workstation, CT is more accurate and reduces risk of erroneous inputs. As the geometric complexity increases, the value of CT for geometric acquisition increases substantially. Fundamentally, CT provides a digital overdefinition of the component which then needs to be reduced in the workstation. However, it is much easier to delete data in a workstation than input additional data, which is why the use of CT data generally provides a cost benefit.

6.2 Recommendations

CT should be used as the method of choice for digital geometry acquisition, particularly when internal measurements are required. The development of additional tools for evaluation of CT contours in multiple material samples and software for transferral of CT data from various CT systems to various CAD workstations should be developed.

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